5.—MINERALOGY OF THE FINE SANDS OF SOME PODSOLS, TROPICAL, MALLEE, AND LATERITIC SOILS.

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TABLE OF CONTENTS.

INTRODUCTION.

The identification of mineral grains in the fine sands of soils is an interesting study in itself, but it has a practical application in that it gives some indication of the processes which result in the formation of a soil, and often of the parent rock of that soil.

The unit of soil study is the profile (a vertical section from the surface of the soil to the underlying parent material as seen in the field) the development of which largely depends on climatic conditions and topography, but "The properties of the rock pass on to the soil, either wholly or in part. The soil afterwards acquires new properties. Consequently we must distinguish between *inherited* properties and such as are *acquired*. These two sets of properties stamp the soil as a living object . . . . . ." (J. van Baren, 1928, p. 161.)

The inherited properties include mineral fragments, which are found principally in the sand fractions, while the acquired properties will be found in the silt and clay fractions, and are formed from the original minerals of the parent rock by weathering, or acquired from outside sources. Sometimes the acquired features of soils are of more importance than the inherited, as is exemplified by certain Mallee soils of Western Australia, which owe their characteristic features to the accumulation of cyclic salt (Prescott, 1931, p. 16). (Mallee soils are alkaline soils formed under low rainfall (10-15 inches). They vary from sands to clays and have an accumulation of calcium carbonate in the subsoil at a depth of 8 to 20 inches. (Teakle, 1929-30, p. 83.)

Climate was once thought to be the most important factor in the production of soil types (Glinka, 1928), for it causes, over large areas similar conditions of temperature and moisture, under which the complex changes in the rock debris take place. Climate will undoubtedly greatly influence the physical condition and the profile; for example, a podsolised granitic soil differs from a granitic soil in a Mallee area, but variation in the bedrock is the main factor in producing sands, clays, loams, etc., and indeed, podsols only attain perfect development where the soils are sandy. Clay material in podsol soil zones does not form a podsol. Differences in parent material are often manifested by variation in the natural vegetation, and are more definitely brought out by detailed soil mapping. Thus in the Kuitpo district of South Australia (Taylor and O'Donnell, 1932) the various soil types are clearly dependent on the underlying rock and the topography.

The inherited properties, if the soil has not been completely changed during formation, indicate the nature of the parent material, and determination of the fine sand minerals should be a quick method of finding out the parent rock, but this is complicated by the great variety of rock types which grade into each other (this applies to the igneous and metamorphic rocks), and by changes which have taken place either in the first stages of rock weathering, or in the soil itself, the less stable minerals quickly disintegrating and giving rise to secondary minerals which are often difficult to identify with certainty (*e.g.,* clay minerals). The older a soil the more its character differs from that of the parent rock and the greater the accumulation of stable accessories, and secondary minerals, provided the parent rock will continue to respond to weathering. A sandstone soil newly weathered would not differ much from an old sandstone soil.

Stable minerals, the stress minerals of Harker, are useful when considering type soils developed from rocks of different composition. The tabulated results in this paper show that these stable species are present in nearly all the soils examined, but they are present in varying amounts. A "flood" of zircon would not be expected from a basic rock, nor one of magnetite or ilmenite from a granitic rock. Ferromagnesians may be accessories in soils from granitic rocks, will form an appreciable part of soils from basic rocks, but will be absent, or practically absent, from ancient soils, as for example, lateritic soils.

Not only is the amount of any species in a soil of importance, but also the forms developed. Zircon from different localities is often of distinctive appearance. The zircons in the King Island soils are readily distinguishable from those found in the Mallee soils of Western Australia.

The change of sedimentary rocks to soils involves, as a rule, mechanical and physical, rather than chemical processes, but residual limestone soils are an exception. Where the parent material of a soil is a sediment, *e.g.*, Myponga sand, it is impoverished in species.

The *acquired* properties of soils are difficult to interpret, and yet, when correctly interpreted, give the key to the processes of soil formation. These features will indicate, by the kind of secondary grains formed, the type of weathering to which the soil has been subjected. In identifying these acquired properties one must remember that the minerals of the fine sand are the remains of parent rock minerals, and that they have given rise to the materials of the silt and clay fractions by the action upon them of the soil solution containing acids and bases. The soil solution depends on the weatherable minerals in the soil and on the climate and topography for its chemical composition. The soil water from a low-lying area is not the same chemically as that from a hill-top or elevated tract of country. The soil solution will act on any unweathered minerals in the mineral residue thus promoting further soil formation. The process must be very slow, even geologically speaking. A mature soil is one which has lost practically all its unstable grains, whether these have been changed into the clay complex, or into more stable forms, such as leucoxene and anatase from ilmenite.

Kaolinisation is one of the most important weathering processes. "Kaolinisation in the strict sense of the word is to be attributed to some form of hydrothermal action, and it can therefore scarcely be looked upon as a normal form of weathering, but impure kaolinic clays, often called lithomarge, either white (pot-clay and pipe-clay) or stained various colours by the oxides of iron or manganese, do result from what appears to be normal weathering" (Rastall). G. W. Robinson ("Soils" 1932) states definitely "that kaolin, whose characteristic mineral is kaolinite, is the product of deep-seated hydrothermal decomposition, which differs entirely from the epigene processes whereby soils are formed." "The kaolinisation theory is inadequate as a general explanation of the clay complex, although the clay complex may contain kaolinite or minerals similar in constitution to kaolinite, formed by epigene processes." C. S. Ross (1927) stresses the fact that the essential clay mineral found in soils is beidellite, a member of the montmorillonite group with the formula, $Al_2O_3 . 3SiO_2 + 4H_2O \pm$. Of kaolinite he states, "It is usually, if not always, the result of action of hot mineral-charged solutions that escape from cooling igneous masses, and can be almost completely eliminated as a possible soil or shale component." In a later paper with Kerr (U.S.G.S. Prof. Paper 165—E) it is stated that "The less profound weathering conditions seem very commonly to produce beidellite-like material, but where the weathering and leaching are very profound kaolinitic material may be produced."

In some soils true kaolinisation appears to have taken place. A soil developed from recent volcanic material from Java is a possible example, as it has been deeply weathered and contains vermicular crystals of kaolinite at depth (156a, b, c, d); 156a may represent the weathered volcanic material itself. Maxwell, quoted by Prescott (1931, p. 70) in discussing the basaltic soils of Hawaii, suggested that the basalt had received a preliminary weathering (surely alteration, not weathering) while in the form of lava under the action of volcanic steam and sulphurous acid. The fact that the weathering is much more complete at the base than at the top of the profile studied, and that species occur at the top which are absent lower down, to a certain extent confirms Maxwell's views. It is thought that a similar process might account for the red loams formed from basalts in the Eastern States (Australia) (Prescott, 1931), and although mineralogical features indicative of this process were not recognised in the samples (906, etc., Carroll, 1931-32) examined microscopically, soil from several feet below the surface might resemble that from Java.

Small grains found in the light fractions of soils (described in a later part of this paper) have resulted from the alteration of the original minerals of the soil. The optical properties of these grains vary slightly from one locality to another, and there is evidently a relation between the type of clay mineral and the climatic and other physical conditions under which it is formed (Ross, 1927). This variation has been noticed in the samples examined, the clay minerals even varying in different parts of the same profile (see percentage composition of Lake Brown light fraction).

Leucoxenic alteration.—Leucoxene is generally considered to be a variety of sphene produced by the alteration of ilmenite, as is to be seen in many rocks. Because of its composition, lime is necessary for its formation, and this suggests that it may be possible for leucoxene to form in soils rich in lime. Leucoxene is an abundant constituent of some heavy fractions of fine sands, but not all soils containing lime and plenty of ilmenite have a large development of leucoxene. Under acid conditions anatase and brookite will form from titania in the soil solution, but it is not considered likely that leucoxene could form directly in this manner. All the leucoxene in a soil may not have formed in situ, the parent rock having contributed most of the grains. The soils from King Island, Tasmania, provide an interesting example of the variation of leucoxene content with topography. Three types of sandy soil from the island, all very similar mineralogically, and evidently derived from similar parent material, were examined. The *Pegarah* fine sandy loam (see later part of this paper) contains abundant ilmenite, and but little leucoxene; the *Naracoopa* sand, over deep, well-drained sand, while similar in other respects, has a fair development of leucoxene and rutile; the *Lappa* sand, over deep sand, poorly drained, differs from the two previous types in the abundance of leucoxene, which in the surface soil is twice as plentiful as ilmenite, and in the three lower horizons is practically equal in amount to ilmenite. This suggests that ilmenite has given rise to leucoxene under acid conditions, although a certain amount of carbonate was probably contained in the dune sands from which this soil was derived. Possibly acid conditions are necessary to liberate the lime. A chemical analysis is needed to show whether the soil now contains lime which, under a continuance of favourable conditions, would combine with titania to form leucoxene. The leucoxene only indicates that the conditions were favourable for its development; or that the parent rock contained leucoxene which it passed on to the soil. That most leucoxene seen in soils is formed there is suggested by the fact that in rocks leucoxene does not usually occur as small rounded grains, but as angular replacements of ilmenite, and these have very seldom been seen in soils even when their presence would be expected.

It is interesting to note in this connection, that at certain pH values many properties of soil constituents are defined. (Prescott, 1931, p. 25.) Precipitation of aluminium silicate takes place at pH 4, and precipitation of $Fe(0H)_2$ at pH 5.5. Silica gel will form between pH 5.5 and pH 8.0. "The solubility of alumina as affected by reaction is probably of great importance in determining the progress of rock weathering. Only in extremely acid or extremely alkaline conditions would the complete break-down of the alumino-silicate nucleus be expected, and the presence of free alumina in lateritic soils indicates that conditions of high acidity probably prevailed at the time the laterite was in process of formation."

Titanic acid is somewhat similar in nature to silicic acid; both occur as colloidal solutions and form gels, so that one might expect a similar pH range for the precipitation of titania as for silica. It is known that from colloidal solutions of silicic acid within the soil opaline silica and finally crystalline quartz can form. Meta-titanic acid in granules has been observed in kaolins; these granules would crystallise as anatase or possibly rutile. The range for formation of titania gel may be very nearly the same as that for silica gel (pH 5.5 to pH 8.0), but from actual examples of crystallisation in situ (Brammall & Harwood, 1923) it appears that the pH would be lower, possibly pH 3 or 4. If leucoxene can occur authigenically in soils then the presence of lime would cause an increase of the pH, but if the titania gel has a considerable pH range, then the tendency to crystallise as anatase would probably be stronger than the tendency to unite with lime to form leucoxene. Abundant lime with a little titania gel would be more favourable for leucoxene formation, than abundant titania gel and a little lime. Soils with plentiful leucoxene have probably passed through a stage when the leaching of lime originally present was prevented. If the reaction was acid and the drainage good, then the lime would be leached out. In lateritic soils therefore, leached tropical soils, and podsols, it is to be expected that, other conditions being equal, there will be a smaller development, if any, of leucoxene than in more alkaline soils. But it must be remembered that ilmenite is a fairly stable mineral, and even with favourable conditions the change would be slow. Titanic acid for these reactions may also be derived from the disintegration of mica, hornblende, or titaniferous augite.

Iron solutions.—Another process of importance in soils and due to the climatic zone in which they occur is the transfer and precipitation of iron solutions. This is illustrated by the hard-pan or ferruginous B. horizon often found in podsols, which (in Australia) develop typically in sandy coastal regions. Mineralogical examination of such soils shows that there is a definite ferruginous band developed some distance below the surface. Often the iron is present in little grains of fairly high refractive index, referred in this paper to kaolinised material, possibly nontronite. Ferric hydroxide is the stable form in which iron is found in the soil. Prescott (1931, p. 22) states, "The downward movement of the iron (in podsols) may be affected in three possible ways: the solution of the iron in the ferric ionic state, the preliminary reduction to the ferrous state followed by solution, and the peptisation of the ferric hydroxide and its movement in the soil in this form. Such a colloidal solution would be held up by a clay illuvial horizon acting as a semi-permeable membrane, or would be precipitated in the lower horizons or at ground water level." "The critical soil reaction would be about pH 3 for the solution of ferric hydroxide, pH 5.5 for the solution of ferrous hydroxide, and pH 6.6 for the peptisation of colloidal ferric hydroxide." Humus and colloidal silica may act as peptising agents. Whatever the cause of the transfer and deposition of iron oxides, it can be recognised microscopically in many soils, *e.g.*, those from the Hundred of Kuitpo, S. Australia, and without further examination it is recognised that leaching as seen in a typical podsol has taken place.

That some soils contain magnetite and others ilmenite may in part be due to differences in parent material, but weathering has also some influence. Soil formed by the breaking down of a hard lateritic formation, such as those found in parts of the interior of Western Australia, are more likely to contain magnetite than are some other soils, because the original iron constituent will have become dehydrated by continual baking during the long dry summers.

Alunite formation.—A process which has been recognised in some of the mallee soils of Western Australia is the formation of alunite at depth (H. Bowley, Annual Report of the Chemical Branch, Mines Dept. W.A., 1932, p. 8). In a typical occurrence at Lake Brown the surface soil is salty. Salt in Australian soils is thought by Prescott (1931, p. 16) to represent the balance between cyclic salt brought inland by wind and rain, and that removed by drainage under conditions of normal rainfall. Acid conditions appear to be necessary for alunite formation, as it has been found at depth where the pH is low. The parent material most probably supplies the potash. Aluminium silicate is precipitated at pH 4.0 and this may have something to do with the occurrence. It is possible that the necessary sulphate may have been supplied by gypsum or other salts, more complex, in times of heavy rainfall, in the circulation of ground water. Alunite grains have not been recognised in soils, and indeed, would not be expected where the samples have been subjected to acid treatment. The Lake Brown soils, and others similar mineralogically, contain small grains most probably of clay material which differ from those found in soils developed in other soil zones.

The following study of the mineral grains identified in a series of fine sands of soils from Western Australia, South Australia, Tasmania, Java, Borneo, and Japan is offered as a contribution to the study of the processes outlined above. The work was done at home (in Bunbury) in 1932, and was revised in the early part of 1934 at the Department of Geology, University of Western Australia, while holding a Hackett Research Studentship.

The chief objects of this investigation were to find out if there is any relationship between the climatic conditions during soil formation, and the changes which some of the less stable primary soil minerals undergo, and whether a study of the occurrence of secondary soil minerals would be of any assistance in tracing the history of a soil, or indicating the climatic conditions of its formation.

The investigation followed similar lines to that already completed (Carroll, 1931-32).

II.—SOURCES OF THE MATERIALS.

The fine sands of soils from the Hundred of Kuitpo, South Australia; King Island, Tasmania, and two samples from Japan were kindly sent over from the collection of the Waite Institute, Adelaide, South Australia, by Professor J. A. Prescott.

A series of red clay soils from Java and Borneo were kindly given to the Department of Geology by the late Professor J. van Baren, Agricultural University, Wageningen, Holland.

The samples of Western Australian soils described in this paper were obtained through the courtesy of Dr. L. J. H. Teakle, Department of Agriculture, Perth, and Mr. B. L. Southern, Government Chemical Laboratory, Perth, Western Australia

In the tables the samples are numbered, and the depth of sample given. The sample numbers of the Eastern States soils refer to the catalogue of the Waite Institute, Glen Osmond, South Australia; those of the West Australian soils to the catalogue of the Government Chemical Laboratory. The East Indian sample numbers are those given by the Museum, Geological Institute, Agricultural University, Wageningen, Holland.

III.—METHOD OF EXAMINATION.

Most of the samples used in this investigation were the fine sand residues from mechanical analyses (0.2 — 0.02 mm. International Mechanical Analysis standard). As the red clay soils from Java and Borneo, and the soils from Manjimup, Western Australia, had not been analysed mechanically, the following procedure was adopted in order to obtain the fine sands required for microscopic examination: the samples were deflocculated by boiling with water to which a little ammonia had been added, and the silt and clay fractions decanted and allowed to settle in tall beakers, to which a little acid was added to hasten the sedimentation. Silt and clay were very difficult to remove from the tropical soils, while coarse sand and gravel were inconspicuous. The results of this rough mechanical analysis for the tropical soils were:—Silt and clay about 90 per cent., coarse and fine sands about 10 per cent. These soils were very ferruginous, and, owing to the high clay content, when dry formed hard lumps.

The fine sands of all samples were cleaned by boiling gently with a 5 per cent. solution of oxalic acid, and panned to reduce the bulk before separation into light and heavy fractions with bromoform (S.G. about 1.8). Panning alone was found to give a sufficiently clean separation into two fractions for microscopic examination of many of the fine sands, e.g., those from King Island Where the heavy fraction was fairly large in amount, magnetite was tested for with a magnet, and was removed before a mount was made in clove oil (refractive index, 1.53).

In order to obtain an accurate idea of the mineralogical composition of the fine sands, the number of grains of each species present in each mount of heavy fraction was counted, this being facilitated by using a mechanical stage and a micrometer eyepiece. The percentage composition of the heavy fractions was obtained, and from these figures the following frequency numbers were allotted to the species according to the method used by the Burmah Oil Company (Evans, Hayman, and Majeed, 1933).

Frequency.	Approximate Percentage.
8+	90—100
8	75—89
8—	60—74
7+	45—59
7	35—44
7—	28—34
6+	23—27
6	18—22
6—	14—17
5	7—13
4	4—6
3	2—3
2	1—2
1	½—1
1*	One grain only.

Although the percentage and actual numbers of grains counted are interesting, the frequency numbers are more easily followed in the tables.

If there was only a small amount of heavy fraction, it was all mounted, *e.g.*, Burbrook sand, while if there was abundance of material one mount was made, and the remainder used for determination of refractive index, etc.

The mineral grains were identified by the usual optical methods, and compared with a standard set of detrital grains.

IV.—MINERALOGY OF THE FINE SANDS.

A.—SOILS FROM PODSOL ZONES.

(i).—HUNDRED OF KUITPO, SOUTH AUSTRALIA.

The Hundred of Kuitpo is situated in the hills east of Adelaide, Lat. 35° 12′, Long. 138° 48′. The soils of the southern part of the Hundred were mapped by Taylor and O'Donnell (Trans. Royal Soc. S. Australia, 1932). The main features of the district are "the sharply-defined quartzite ridges forming the eastern and western boundaries of the Hundred, and the intensely dissected, steep-sided, flat-topped remnants of the ancient peneplain which originally covered the whole area between the bounding ranges." The annual rainfall is 35 inches, 25 of which fall between April and September. The following descriptions of the soil types are taken from Taylor and O'Donnell.

Meadows clay loam: An alluvial dark grey to black soil overlying heavy clay. Occurs only in valley bottoms.

Meadows sand: A grey to white sand or coarse sand overlying yellow heavy clay.

Myponga sand: A deep podsolised grey to white sand overlying yellow sand over sandstone. A distinct typical coffee-brown layer is often present between 30-60 inches.

Kuitpo gravelly, sandy loam (lateritic): Grey to yellow sandy loam, with varying content of ironstone gravel over yellow friable clay with ironstone gravel.

Burbrook sandy loam: Grey sand or sandy loam over buff loam or friable clay over rock (schist and quartzite). Frequently stony and shallow soil.

Kondoparinga loam: Brown loam, sometimes moderately high in silt over phyllites.

KUITPO GRAVELLY, SANDY LOAM (lateritic origin).

Samples 146 (0-7″); 147 (7-14″).

Light fraction.—The light fractions consist principally of angular to sub-angular grains of quartz with small inclusions of apatite, zircon, and gas bubbles. Felspars and spicules* were found in 147 but not in 146. The 0-7″ horizon contains a little kaolinised material which is more plentiful in the 7-14″ horizon where it has a yellowish brown colour and a "fluffy" appearance. These grains may be nontronite in part. (?)Nontronite is the

* For this and subsequent references see Carroll, 1931-32.

name given to certain small secondary grains found in the fine sands. These grains may be irregular or rounded, and range from practically colourless to bright brown, and from opaque to translucent. Some will give faint interference figures. When boiled in HCl or oxalic acid the brown colour is removed, but the grains are not wholly destroyed. Malachite green stains them readily, and boiling in KOH (20%) will often dissolve the grains. The refractive index is usually about 1.56, often slightly higher, rising to 1.59.

Heavy fraction.—Iron and titanium minerals make up the bulk of the heavy fractions. Of the subordinate minerals, the more interesting are zircon, tourmaline, and sillimanite, the latter accounting for 10% of the heavy fraction in sample 146.

Samples 1932 (0-12″); 1933 (12-24″); 1934 (24-30″).

Light fraction.—The light fractions consist mainly of quartz grains. In the surface 12″ the grains are small, angular, clear and colourless but in the 12-24″ horizon the grains are larger and more rounded, while in the lowest sample the grains are large and about half-round. Some of these contain beautiful sagenite webbing of rutile. Kaolinised material, possibly nontronite, is much more abundant in the lower horizons than at the surface. These grains give colour to the fine sand, and are not appreciably altered by treatment with weak acid. Felspar is very scarce, a few grains doubtfully referred to orthoclase were found in 1932, but not in the other light fractions of this profile. Muscovite was quite commonly found in the light fractions; because of its flaky character it failed to separate with the other heavy minerals. Spicules were abundant in 1932, common in 1933, but very scarce in 1934.

Heavy fraction.—All the samples have an abundance of heavy minerals. 1932 has hundreds of grains which appear to be ilmenite altering to rutile. The ilmenite grains are black and opaque with a metallic lustre; rutile is found in bright reddish patches on the surfaces of these grains. This ilmeno-rutile is less well developed in 1933 and 1934. The principal subordinate minerals are zircon, in small, rounded, prismatic grains; and tourmaline in pinkish-brown, broken and irregular crystals, with a few grains of sillimanite and kyanite.

Samples 1846 (0-7″); 1847 (10-14″); 1848 (14-21″); 1849 (21-27″).

Plate IV., Fig. 1.

Light fraction.—Quartz in clear, colourless, angular to sub-angular grains makes up the bulk of the light fraction. The surface sample contains a few rounded grains, but there is less in the lower parts of the profile. Brown iron ore (? hematite), rutile (?), apatite and gas bubbles were found as inclusions in the quartz, but most of the grains were free from inclusions. Felspars were not found in the lower parts of the profile, but a few grains were found in 1846, one showed faint twin lamellae, while another had microcline twinning. Kaolinised material was common in the surface layer and increased with depth. In 1849 it was abundant in small, bright yellow grains, the refractive index of which was about 1.59. It has been referred to (?) nontronite. Muscovite was fairly common.

Heavy fraction.—In the heavy fraction, as in all the samples of this gravelly, sandy loam, ilmenite, rutile and leucoxene are the principal minerals. Subordinate minerals are not plentiful, and differ from those already described only in the abundance of mica.

BURBROOK SANDY LOAM.

This soil is probably derived from schists or quartzites. Samples 148 (0-9″); 149 (9-13″). Plate IV., Fig. 2.

Light fraction.—Quartz is the predominating mineral of the light fraction; it occurs in clear, colourless grains of two distinct sizes:—large half-round to sub-angular grains, and smaller angular grains. In the lower sample there are fewer rounded grains than in the surface soil. Inclusions are scarce, only a few minute rods of apatite being found. Felspar is scarce, only a few grains of orthoclase being found. Kaolinised material is not plentiful, but spicules were fairly numerous. Small crystals of zircon, tourmaline, and biotite failed to separate with the rest of the heavy minerals.

Heavy fraction.—Iron and titanium minerals make up the bulk of the heavy fraction. There are two varieties of rutile:—one, reddish brown, was probably formed in situ from ilmenite; the other is yellowish brown. The grains tabulated as limonite are possibly partly rutile, or a mixture of decomposed iron and titanium compounds. Tourmaline and zircon are the most plentiful of the remaining minerals, while biotite failed to separate and was left with the light minerals.

MYPONGA SAND (over sandstones).

Plate IV., Fig. 3. Samples 227 (0-9″); 1924 (0-20″); 1925 (20-30″).

Light fraction.—The light fraction, consisting mainly of quartz, makes up the bulk of the fine sand. Many of the quartz grains are rounded in 227, well rounded in 1924, but angular for the most part in 1925. The angular grains are small and clear. The rounded grains of 1925 are much larger than the angular ones, and are often dull and clouded. Zircon, rutile, and (?) apatite were found as inclusions. Untwinned felspar, probably orthoclase, was found in 227, but not in the other two samples. Kaolinised material was found in 1925 as dull yellowish-brown translucent grains, some of which gave a faint biaxial figure. These grains were not plentiful.

Heavy fraction.—In each sample there is only a small amount of heavy fraction, about half of which is accounted for by the iron and titanium minerals. Tourmaline and zircon are interesting, as they occur in large, rounded grains, showing that they have suffered much wear. A few grains of andalusite, kyanite, sillimanite, epidote, and garnet were also found.

MEADOWS SAND (alluvial).

Plate IV., Fig. 4. Samples 1917 (0-12″); 1918 (12-30″); 1919 (30-42″).

Light fraction.—Quartz is the principal mineral of the light fraction, and occurs in small, fresh-looking, angular fragments, and in larger, round to sub-round grains containing inclusions of rutile (sagenite webbing), zircon and (?) apatite. The majority of the grains are angular. Felspars are scarce and occur in very small fragments. Kaolinised material was found in 1918 and 1919 and had a similar appearance to that already described. Spicules were plentiful in the first horizon, numerous in the second, and but sparingly present in the third horizon.

Heavy Fraction.—The heavy fractions are fairly abundant and present some interesting features. In the first sample (0-12″), rutile and ilmenite are the predominating minerals, and leucoxene is subordinate. In the second sample (12-30″), pure ilmenite is less plentiful than rutile and "limonite."

The term "limonite" is reserved in this description for grains which cannot readily be classed as ilmenite, leucoxene, rutile or mixtures of these. In the third horizon (30-42″), ilmenite and rutile are about equal in amount, with about half as much leucoxene. In addition to "limonite" there is a "flood" of semi-opaque, alteration product, which has the same features as noted in the light fraction. Of the accompanying minerals, sillimanite is the most plentiful, being followed by tourmaline and zircon, the latter in small, rounded prisms showing much wear. A few grains of anatase, epidote, biotite, kyanite, ? andalusite, and augite were also identified.

MEADOWS CLAY LOAM (alluvial).

Samples 1929 (0-4″); 1930 (4-20″); 1931 (20-36″).

(Plate IV., Fig. 5.)

Light fraction.—Quartz makes up the bulk of the light fraction and is present in clear, angular to sub-angular grains, with a fresh and completely broken appearance. In the second horizon (4-20″) the grain size is larger, but in the third is similar to the first. Felspar was not found in the surface sample, but a few grains were identified in the lower horizons. The grains were untwinned, but owing to the smallness of their size cannot be referred with certainty to a particular species, though they are probably orthoclase. Kaolinised material is present in the lower horizons, and is similar to that already described. Spicules and allied small organic remains are very common, and make up an appreciable part of this fraction in the surface sample; they are less plentiful in 1930, and only sparingly present in 1931.

Heavy fraction.—The heavy fraction is small in amount and the iron and titanium minerals make up less than 50% of the heavy minerals. Muscovite and biotite are prominent in this soil, making an important distinction between the Meadows clay loam and the Meadows sand. Biotite is the most plentiful mineral of the 20-36″ horizon, while muscovite is common throughout the profile. Tourmaline and zircon are the most conspicuous of the remaining grains identified. Tourmaline occurs in very small, grey prisms, often with one end broken. The tiny crystals have the appearance of having been inclusions in other minerals, *e.g.* quartz, from which they have recently been released. The zircon crystals seem to have had the same origin. A few grains of anatase, kyanite, hornblende, and sillimanite were also identified. The samples were difficult to examine on account of the extremely small size of the grains.

KONDOPARINGA LOAM

(over micaceous schists and phyllites).

Samples 1926 (0-2″); 1927 (2-9″); 1928 (9-15″).

(Plate IV., Fig. 6.)

Light fraction.—Quartz makes up the bulk of the light fraction. It is in very small, clear, angular to sub-angular fragments. In the third sample (9-15″), larger, more rounded grains occur as well as the small angular fragments. Inclusions seen were minute zircons, and tourmalines similar to those found in the heavy fraction. Felspar is scarce and occurs in small, angular grains of a pinkish colour, only to be distinguished from quartz by the refractive index. It is probably orthoclase. Spicules were very abundant throughout the profile.

There are three kinds of mica present:—muscovite, biotite, and a greenish-yellow mica which may be altered biotite. The micas, owing to their small size and flaky character, failed to separate with the other heavy minerals. Kaolinised material was not identified in this soil.

Heavy fraction.—The most noticeable feature of this soil is the scarcity of heavy minerals. The greater part of the heavy fraction is made up of ilmenite and rutile, the latter having a greater development than leucoxene. Anatase is conspicuous in the second and third horizons in small, gray-blue prisms. The grain size is, on the whole, very small, although some of the ilmenite grains are large. The appearance of the mounts are similar to those of the Meadows clay loam. Of the remaining minerals, sillimanite, garnet, and mica are conspicuous, while some samples contain a few grains of kyanite, hornblende, and epidote. Tourmaline and zircon occur as in the Meadows clay loam.

KING ISLAND, TASMANIA.

King Island is situated in Bass Strait between Victoria and Tasmania. Lat. S. 39° 50′, Long. 144° 0′ E. A soil survey has been made by Stephens and Hosking (Bull. 70, C.S.I.R. Australia, 1932). Eight types of soil were identified, the fine sands of three of which, the Pegarah fine sandy loam, the Naracoopa sand, and the Lappa sand, are described below. The rocks of the island include sediments (Recent, Tertiary, and early Palaeozoic), while there is a small development of granite, dolerite, and basalt. The sand dunes on the west side of the island are an important feature.

The *Pegarah fine sandy loam* is associated with the plateau of the island, and it originally carried sclerophyll forest. It is considered to be a residual soil from the country rocks which are slates and schists.

The *Naracoopa and Lappa sands* are closely connected with the Pegarah type. The Naracoopa sand occurs on the inland dune formations at high levels on the eastern coast. It is known as "Fernbank" as it carries thick growths of bracken. The Lappa sands are found in troughs between the dunes (Naracoopa) and the Pegarah tablelands. It is thought that these sands are associated with and derived from the extensive denudation of the Pegarah fine sandy loam. The drainage of the Lappa sand is poor.

PEGARAH FINE SANDY LOAM.

(Timber type (?) over parent rock.)

Samples 2225 (0-6″); 2226 (6-13″); 2227 (13-45″).

Light fraction.—Quartz is the principal mineral of the light fraction. The grains are clear, colourless, angular to sub-angular, and show little evidence of transport, although a few larger rounded grains are also present. Many grains have a broken, pitted appearance, while others are cloudy. Minute zircons, tourmalines, iron ores, (?) apatite, and sillimanite rods were noted as inclusions. Felspar was fairly plentiful in the surface sample, but not so abundant in the other horizons. It has been referred to orthoclase as the refractive index is just below 1.53, and the grains are untwinned. A few grains were identified as microperthite. All the felspar grains were fresh and unclouded. Kaolinised material was found only in the third horizon (13-45″). These grains are pale yellow-brown to almost colourless, and are probably similar to those described from the Kuitpo samples. Spicules are sparingly present throughout the profile, though there are not many in the lowest horizon.

Heavy fraction.—The heavy fraction is very plentiful and characterised by a "flood" of ilmenite (over 70 per cent.). Leucoxene is a little more abundant than rutile, but both are very subordinate to ilmenite. There are only a few grains of magnetite. Andalusite, tourmaline, and zircon are the most abundant of the remaining minerals. Andalusite occurs either in prismatic grains or broken fragments, the larger grains being very pleochroic in 2226. Tourmaline occurs in sharp-edged, brown prisms with many inclusions, rounded basal sections and broken fragments. The zircons are in fairly large, stout, prismatic crystals, some quite clear, others zoned and with many inclusions. Garnet is interesting because several perfect, dodecahedral crystals were found, particularly in 2227 (13-45″). A few grains of muscovite, anatase, sillimanite, kyanite, and epidote were also found.

NARACOOPA SAND.

(Fernbank types—over deep sand, well drained.)

Samples: 2232 (0-13″); 2233 (13-60″); 2234 (60-80″).

(Plate V., Fig. 7.)

Light fraction.—In the light fraction the quartz grains vary from subangular to well-rounded; the grains are very uniform in size, and many are equidimensional. There are a greater number of rounded grains in the second and third horizons than in the surface soil. The only inclusions found were rutile and gas bubbles. The appearance of this fraction is very similar to that of the Esperance sands (Carroll, 1931-32). Grains with a fresh appearance and refractive index slightly below 1.53 have been identified as orthoclase, acid plagioclase, and mirocline. In 2233 the felspar grains are more rounded than in the surface soil, but are less rounded than the quartz. Kaolinised material was found in the second and third horizons as small, yellowish brown grains. Spicules were not found.

Heavy fraction.—The heavy fraction is very large, and consists of over 50 per cent. of ilmenite. Leucoxene and rutile are present in about the same amounts, though leucoxene is slightly less than the rutile, which is the reddish brown, prismatic variety. Zircon is very conspicuous, and makes up 25 per cent. of the heavy fraction in the surface sample, but rather less in the other horizons. It occurs in several distinct habits:—well-worn, prismatic grains; prismatic-pyramidal crystals; and rectangular-prismatic crystals. Associated with zircon are grains of an appearance somewhat similar to the first zircon type, but with a slightly pitted surface and a pale green colour. These grains have been referred to monazite. The few remaining grains are similar to those already described (from the Pegarah fine sandy loam), with the exception of kyanite, which is in well-worn grains in contrast to the fresh andalusite. Garnet is in irregularly fractured fragments of a pale, pinkish brown colour.

LAPPA SAND.

(Plain type—over deep sand, poorly drained.)

Samples: 2241 (0-9″); 2242 (9-38″); 2243 (38-50″); 2244 (50-80″).

Light fraction.—In the light fraction, quartz predominates in angular to half-round grains. Most of the grains contained no inclusions, but those noted were, rutile, iron ores, tourmaline, zircon, and gas bubbles.

The grains were more angular towards the base of the profile, and cloudy grains were fairly common. Felspar was inconspicuous in the surface soil, but present in the lower horizons as small, clear, angular grains, some of which showed faint twin lamellae. A few grains of muscovite were found in the lower horizons, and spicules were sparingly present throughout. A small amount of kaolinised material was found in the 9-38″ horizon.

Heavy fraction.—The heavy fraction is large in amount and similar to the types already described, but it differs from these in the greater development of leucoxene. In the first horizon it is twice as plentiful as ilmenite, and in the other horizons it is about equal in amount to ilmenite. Rutile diminishes in amount. Zircon is very plentiful in the habits already noted. Tourmaline is very abundant, brown primatic grains predominating, but there are also large numbers of irregular blue grains, while many grains have patchy colours, pink and brown, or blue and brown. Andalusite is mostly in little broken fragments, unclouded, and faintly pleochroic. A few grains of kyanite, sillimanite, garnet, epidote, and anatase were also found, but have no significant features.

The microscopic examination shows that these three types of soil appear to have been derived from the same or similar parent material.

MANJIMUP, WESTERN AUSTRALIA.

(Lat. 34° 16′, Long. 116° 8′).

I.—*Principal timber, Karri* (*E. diversicolor*).

1473	0—9″	top of hill	(G. F. Coomb's holding.)
1474	9—18″	,,	
1475	0—9″	one-third down hill	
1476	9—18″	,, ,,	
1477	0—9″	two-thirds down hill	
1478	9—18″	,, ,,	
1479	0—9″	edge of swamp	
1480	9—18″	,, ,,	

The soil (Karri type) is deep reddish-brown in colour, because of a heavy ferruginous coating on the grains of the fine sand. It is a clay loam, the plentiful clay particles being difficult to remove during sedimentation in tall beakers.

Light fraction.—Quartz is the main constituent of the light fraction, but the grains are much obscured; when fairly clear, they are found to be rounded to sub-angular, with few inclusions. On going down hill the ferruginous (?) limonitic coating becomes denser, but at the edge of the swamp (1479) the grains are much cleaner. Orthoclase and plagioclase are present in some samples, but are difficult to determine. Large angular grains of kaolinised or seriticized felspar were found in 1475, and in 1476 there were a few grains of plagioclase, possibly labradorite. (?) Nontronite is scarce; it occurs in small grains, some of which are reddish-brown while others are much paler. The greatest number of these grains were found in samples from two-thirds down hill (1477 and 1478). Spicules were fairly plentiful throughout.

Heavy fraction.—All the samples contained an abundance of heavy minerals. Most of the ilmenite grains, which make up over 90 per cent. of each heavy fraction, were covered with ferruginous material, most probably limonite. This is of a bright reddish-brown colour, and when the grains are heated in a closed tube water is given off, and the grains change from brown to black. Before heating very few grains would respond to a magnet, but afterwards about half were readily removed in this way. Leucoxene is not abundant in any of the samples, suggesting that the black mineral grains are magnetite rather than ilmenite, but it is difficult to draw the line between dark-coloured leucoxene and pale limonite. Zircon is the only other mineral of any importance. It occurs in small, rounded, prismatic crystals, often brown in colour. A few grains of rutile and tourmaline were found in some of the samples. At the edge of the swamp (1479 and 1480) the minerals indicate that there is a slight mixture with the Red Gum type found on the next hillside, and described below.

II.—*Principal timber, Red Gum (E. calophylla).*

1481	0—9″	edge of moist land.	(H. C. Barnsby's holding.)
1482	9—18″	„	
1483	0—9″	top of hill.	
1484	9—18″	„	

Plate V., Fig. 8.

The soil (Red Gum type) is much more sandy than the Karri type and is light yellow in colour. The clay and silt fractions are small in amount, the soil being a sand or sandy loam.

Light fraction.—Quartz is the predominating mineral of the light fraction. Large sub-angular to round grains are the most common; inclusions are not plentiful, but some grains have "wavy" extinction. At the top of the hill (1483 and 1484) the grain size is somewhat smaller and all the grains are angular, except some of the smallest, which are round, suggesting that these have been subjected to a certain amount of wear by transport. Felspar is present but difficult to distinguish from quartz. Plagioclase was present in 1841, but orthoclase was not identified. Some of the more obscured grains may be partially kaolinised felspar. (?)Nontronite is present; it is more plentiful at the top of the hill (1483 and 1484) than at the bottom. The obscuring material of these samples is of a dull yellowish grey colour, and not nearly as "heavy" as in the Karri type.

Heavy fraction.—The heavy fraction is interesting since, in contrast to the Karri type, it contains only about 40 per cent. of ilmenite. Leucoxene is plentiful, and zircon is conspicuous, for in the first sample (1481) it makes up about 40 per cent. of the heavy fraction. It is accompanied by kyanite, is worn cleavage fragments, rutile, tourmaline in broken, greyish-blue fragments, bright blue grains and brown to green crystals; garnet, amphibole, epidote, and sillimanite. Zircon is in worn prismatic crystals, mostly of a brownish colour, and with few inclusions. Many of the more elongated grains resemble kyanite on first sight, but most of the grains are stumpy, and some are broken.

From the above descriptions it will be seen that there are two distinct types of soil, both mineralogically and in the field. The Karri type may be a weathered and broken down laterite, which was originally formed over basic rocks. The Red Gum type, on the other hand, is much more quartzose, and may have been derived from an acid granite or a pegmatite, but the presence of a fair amount of kyanite suggests a metamorphic parent rock.

B.—TROPICAL SOILS.

(i).—JAVA.

(a).—*Profile of volcanic material*, collected near volcanoes, Salak, about 20 miles south of Buitenzorg (Lat. 6° 30′, Long. 106° 48′).

156d.	surface soil, depth 1M.	*Plate V. Fig.* 10.
156c.	soil, 2nd layer.	
156b.	soil, 3rd layer.	
156a.	soil, 4th layer.	*Plate V Fig.* 9.

Light fraction.—The light fraction consists principally of kaolinised material and kaolinite, with subordinate quartz and felspar. Kaolinite is most plentiful at the base of the profile (156a), and is interesting as it occurs in crystalline aggregates as illustrated by Ross and Kerr (U.S.G.S. Prof. Paper 165—E). The grains are of a pale yellowish-gray colour, slightly pleochroic, and vermicular. Each grain is made up of numerous tiny fibres, which are parallel to each other. A typical grain was 0.166 mm. long and 0.083 mm. wide. The interference colours are reds and yellows of the first order, and the extinction is practically parallel to the length of the small fibres. Other grains of kaolinite occur in flat plates, sometimes nearly hexagonal. Kaolinised material, possibly nontronite, is very abundant. It is yellowish brown (156a) but becomes darker towards the surface (156d). It is semi-opaque, but some grains are cryptocrystalline and have weak double refraction. *Felspar* is more plentiful than quartz, with which it may easily be confused. It is found in angular, clear grains with refractive index slightly above that of Canada balsam, and may be referred to labradorite. In the surface sample the felspar is present in large irregular grains with "pockets" of brownish, kaolinised material. Similar grains have been illustrated by J. van Baren (1928, Plate IV., Fig. 18). *Quartz* subordinate to plagioclase, is in clear, colourless, angular to rounded grains. An interesting feature is the present of a few euhedral crystals, practically free from inclusions, except for a few gas bubbles. In sample 156c there are more rounded grains than in the other samples. *Chalcedony* was found in small amounts throughout the profile, but is most plentiful at the base. It occurs in small rounded to angular grains with typical spherulitic extinction. It tends to remain with the heavy minerals.

Heavy fraction.—Heavy minerals are abundant throughout the profile. Magnetite and ilmenite are the most conspicuous. Most of the magnetite was easily removed with a magnet, but some remained in the mounts as square or dodecahedral crystals. It was often difficult to distinguish between the remaining magnetite and ilmenite. Leucoxene and rutile are feebly developed, but hematite and mica are noteworthy. Zircon is scarce, only 40 grains being found in 35 full traverses. It occurs mostly in small worn prismatic crystals, but larger grains are sharp-edged and of a pinky-brown colour and quite clear. The surface sample (156d) differs from the other parts of the profile in the presence of hypersthene. After removing the magnetite, hypersthene makes up about a fifth of the heavy fraction. It occurs in large brownish-green, pleochroic prisms and broken fragments, often with inclusions of magnetite or ilmenite (see Plate V., Fig. 10). The whole appearance of the heavy fraction of 156d is altered by the presence of hypersthene, and differs considerably from that of the other heavy fractions of this profile.

Euhedral quartz, magnetite, prismatic pyroxenes, and felspars often with kaolinitic inlets (representing the original glassy matrix) are characteristic features of volcanic materials, even when combined in deep sea deposits. (C. S. Ross, Amer. Assoc. Petrol. Geol. vol. 12; Report of the Challenger Expedition, Deep Sea Deposits, Plate 27, Fig. 4, also numerous examples in the text.)

(b) *Profile of volcanic material* collected away from recent volcanoes Djasinga, south of the road Rangkasbitoen-Sadjina, N.W. of Buitenzorg (Lat. 6° 30′, Long. 106° 48′), Java.

Samples 993b. (0-30 cm. surface soil); 993a. (30 cm. subsoil).

Light fraction.—Kaolinised material and felspar are present in about equal amounts in the light fraction. Quartz, (?)nontronite and chalcedony are subordinate in amount. The kaolinised material is of a pale yellow colour and has a "felted" surface suggesting that mica was the original mineral. A few grains that are clear and translucent may be referred to (?) nontronite. Many felspar grains have a clouded surface due to the development of weathering products. The felspars present are probably two varieties of plagioclase; labradorite, and a more acid member, possibly andesine. The grains are angular and clear. Quartz is mostly in angular grains, many of which are euhedral; some of these contain liquid inclusions. Chalcedony is noticeable in the mounts on account of its light pinky colour and low refractive index, and is more plentiful in the subsoil than the soil. Micaceous aggregates are fairly plentiful as small, rounded grains, possibly derived from the weathering of the felspar. Spicules, rather large and stout, are fairly plentiful.

Heavy fraction.—The heavy fraction, large in amount, consists mostly of ilmenite, with much less magnetite than the surface sample of the (a) series described above; or, at least much less could be removed with the magnet. The only prominent minerals remaining are hypersthene and zircon. Hypersthene is much more plentiful in the surface soil (993b) than in the subsoil, from which it may have been removed or altered by the soil solution. Zircon is scarce; it occurs in small, worn, prismatic grains. Leucoxene and rutile are not conspicuous; leucoxene is in excess of rutile. A few grains of anatase were found in the subsoil (993a).

(c) *Limestone soil,* 1 Km. S.W. of Toeban, Rembang (Lat. 6° 45′, Long. 111° 24′), East Java.

Samples 1000c. (0-15 cm.); 1000b. (15-105 cm.).

Light fraction.—Brownish ferruginous material makes up the bulk of the light fraction. It is semi-opaque and apparently a decomposition product mixed with iron oxide (? ferric hydroxide). When a few grams of the parent rock were dissolved in HCl, similar grains were found in the residue. It gives the colour to the soil, for the subordinate quartz is clear, colourless, and little encrusted with iron compounds. The refractive index of this material is fairly high. A possible explanation is that it is limonite formed by alteration of glauconite, but no grains of the latter mineral were found in the rock, which was a white, dense, unfossiliferous limestone. The quartz grains are mostly angular, but a few are round. Inclusions of gases and rutile were found. In 1000c. the grain size is rather smaller than in 1000b. Felspars seem to be absent, but could be mistaken for quartz. Their presence is suggested by some slightly kaolinised grains. A few grains of chalcedony were also present.

Heavy fraction.—The heavy fraction is made up principally of iron ores. Magnetite is very plentiful, while leucoxene and rutile were not conspicuous. "Limonite," which is possibly a very dark variety of (?) nontronite as it is semi-opaque, and has much the appearance of members of this series, is very strongly developed in the subsoil (1000b.), but there is only a small amount at the surface. The remaining minerals include zircon, hypersthene, epidote, hornblende, (?)augite (possibly hypersthene), sillimanite, and kyanite, the latter in very worn grains. Zircon is in very small worn, brownish prisms, one or two acicular crystals were seen, but the usual type is broken grains. Epidote is rather pale and colourless. Hornblende occurs in typical brownish-green cleavage fragments.

ii.—BORNEO.

Samples 930b. Gabbro soil (surface), Martapoera, Lat. 3° 29′; 1135b. Gabbro soil (surface), Martapoera, Long. 115° 0′.

Light fraction.—In 930b. felspar, probably labradorite, is the main constituent of the light fraction. It occurs in fresh, angular, somewhat rectangular grains and in more rounded grains showing kaolinisation. Where altered, the grains are yellowish-brown in colour and often well-rounded. Quartz and ferruginous material appear to be absent from this soil, but there is difficulty in distinguishing the quartz from plagioclase. "Limonite" (ferruginous material) covers practically all the grains of 1135b. and apparently little was removed by oxalic acid treatment. It is present in fairly large rounded grains, the cores of which may be kaolinised material or felspar. There are, in addition, a few grains of semi-opaque, micaceous material and a little chlorite.

Heavy fraction.—Although both are derived from gabbro, these fine sands differ very considerably mineralogically. In 930b. there is a small amount of heavy fraction which contains over 70% of iron and titanium minerals. Magnetite was not separated from the ilmenite. 1135b. contained a large amount of heavy minerals, about half of which were magnetite, the ilmenite-limonite association being so strong that no traverses were made. In 930b. the abundance of pale to bright green epidote, which made up 20% of this fraction was noticeable. 1135b. contained, in addition to a few grains of leucoxene, fairly plentiful pyroxene of a pale green colour giving extinction angles between 42 and 47 degrees, measured from the long axis of the grains and parallel to the cleavage. The grains are non-pleochroic, and may possibly be referred to diallage or diopside. In 930b. leucoxene and rutile are feebly developed, and the remaining grains of the fraction consist of zircon, tourmaline, (?) amphibole, and garnet, which were hardly represented in 1135b.

Small pieces of the parent rocks were crushed to obtain the constituent minerals. 930 contained a little magnetite, plentiful pale green epidote, a little augite with high extinction angles, and a large amount of brownish decomposed material. 1135 consisted mainly of colourless augite, with subordinate, although fairly plentiful magnetite. The mineral grains remaining in the fine sand show how completely weathered the resulting soil is, when compared to the parent rock.

Soil from peridotite Bandjermasin, Lat. 3° 30′, Long. 114° 38′, Borneo.

Sample: 924c. (surface soil).

Light fraction.—The bulk of the light fraction is made up of small, angular to somewhat rounded grains of a felspar which has a fairly high refractive index, and is therefore plagioclase not more acid than labradorite. It is untwinned, and some of the clearer grains are almost euhedral. The smaller grains are fresh and clear, but the larger are cracked and often show incipient alteration to a yellowish material. Accompanying the plagioclase are grains of a yellowish material which perhaps represents the olivine of the parent rock. These grains are quite irregular, and often have a felted appearance, due, possibly, to the addition of iron compounds. In some grains small cubes of an opaque mineral (? chromite or magnetite) are embedded. The double refraction is very weak, and most of these grains are practically isotropic. A few spicules were found.

Heavy fraction.—The fine sand contains an abundance of heavy minerals, of which magnetite and ilmenite are the most prominent. After the removal of magnetite, the ores make up over 90% of this fraction. Leucoxene is plentiful, but only a few grains of rutile were found. Zircon is the only other abundant mineral; it occurs in fairly large prismatic crystals, capped by acicular pyramids, and is little worn. Some of the grains are irregularly fractured, and a few are quite small. A little epidote failed to separate and was left with the light fraction. Chromite was doubtfully identified microscopically, as opaque grains with brownish semi-opaque thin edges. This was confirmed with the blowpipe, the indication being strong, so that many of the ore grains are probably chromite.

The parent rock, when crushed, was found to contain little other than olivine. The olivine was clear, almost colourless and unaltered, and on weathering has given rise to the large amounts of opaque material in the soil. Possibly some of the clear grains thought to be felspar are actually quartz derived from the olivine by weathering in a situation of intense leaching. In basaltic soils in some parts of Australia olivine persists, so that the alteration is due to the climate under which the soil has developed.

Soil from andesite, Tanahamboengang, Borneo (Lat. 2° 5′, Long. 116° 15′).

Sample: 928b (surface soil).

Light fraction.—In the light fraction most of the grains are obscured by iron compounds, but where fairly clear are seen to be felspar (? labradorite). There are two sizes of grains, the larger from phenocrysts and the smaller from the groundmass of the parent rock. The larger crystals nearly all have a rectangular habit. Yellowish-green chloritic material is also present; it is slightly pleochroic, and one grain seems to be a pseudomorph after augite. Other grains are practically isotropic. Minute, brownish, isotropic material may be the remains of original interstitial glass.

Heavy fraction.—The heavy fraction consists mainly of magnetite with a little ilmenite. Leucoxene, probably mixed with limonite, is conspicuous, but rutile is practically absent. Of the remaining minerals, pale green to colourless augite is the most plentiful. It occurs in rather rectangular grains, some of which have inclined dispersion so that the extinction is not sharp. These grains are brownish and are probably titan-augite. Zircon and epidote are scarce, while there are a few grains of green hornblende.

The parent rock, when crushed, was found to contain abundant brownish-green hornblende, which has practically disappeared from the soil, probably being represented there by the ferruginous opaque grains. The rock was a hornblende andesite, with a little augite and felspars of two generations. The augite was able to persist in the soil on account of its greater stability under conditions of intense leaching.

C.—SOILS FROM THE MALLEE SOIL ZONE, W. AUSTRALIA.

(i.) NINGHAN.

Avon location 579. Lat. 30° 0′, Long. 117° 30′. Plate V., Fig. 11.

Samples:—1634 (0-3″); 1635 (3-12″); 1636 (12-27″); 1637 (27-46″); 1638 (46-72″); 1639/32 (72-75″).

Light fraction.—The light fraction of the surface sample (1634) is made up of about 70% kaolinised material (? nontronite), while at the base of the profile (1639) the amount has dropped to about 15%. At the surface the nontronite is in small grains of a bright reddish-brown colour, but at 72″ it is pale yellow. All the grains are rounded and clearly of secondary origin. Associated with this mineral, and very similar in appearance, are numerous round grains usually of a light colour, and having spherulitic structure as shown by the polarisation. These grains may have the same composition as the ? nontronite. Grains of other minerals, *e.g.* ilmenite, often have a rim of this spherulitic material completely encircling them and the appearance under crossed nicols is peculiar. Quartz is present in fairly large sub-angular to half-round grains rather obscured with iron encrustations, and small angular, clear grains. The larger grains often contain good sagenite webbing of rutile. At the base of the profile (1639) the grains are much clearer than at the top. Orthoclase, plagioclase, and microperthite are fairly plentiful. Orthoclase occurs in small, pinkish "chips," and in sample 1639 is subordinate to acid plagioclase, possibly oligoclase. Twinned grains are in the minority. Some samples contain a few grains of opaline silica, and a few spicules were found in the surface soil.

Heavy fraction.—The fine sand contains only a small quantity of heavy minerals. Ilmenite accounts for about 55 per cent. of the heavy fraction. Leucoxene is well-developed, and there is over 30 per cent. of zircon. In the surface soil (1634) about 10 per cent. of crystallised, authigenous dolomite was found. The subordinate minerals include small amounts of colourless pale green amphibole, rutile, tourmaline, epidote, garnet, and micas (the latter in the lowest samples only). Zircon is in rounded, prismatic crystals, often yellowish-brown in colour. Some grains are zoned, but inclusions are not plentiful. It is possible that some of these grains may be xenotime, as some have a "flat" habit consisting of the unit prism (a) capped by low pyramids. A chemical test for phosphorus is necessary for complete identification as xenotime.

(ii).—SOUTH GABBIN.

Avon location 20289. Approx. Lat. 31° 0′, Long. 118° 0′.

Samples: 1640 (0—2″); 1641 (2—6″); 1642 (6—12″); 1643 (12—24″); 1644/32 (24—36″).

Light fraction.—The light fraction of the fine sand is very similar to that at Ninghan, and consists of about equal quantities of quartz and kaolinised material (?) nontronite, with small amounts of acid plagioclase and orthoclase. Quartz occurs in clear, colourless, angular to sub-angular grains, the smaller ones being always angular. Inclusions are not plentiful, but the larger grains occasionally have sagenite webbing and minute zircons. All the grains are much less obscured than in the Ninghan samples. Kaolinised material occurs as in the Ninghan fine sand. This (?) nontronite gives the colour to the fine sand. Felspars occur in small, pinkish "chips" and are fairly plentiful at the base of the profile, but not so abundant at the surface. Orthoclase and an acid plagioclase are both present. The plagioclase is possibly oligoclase, while a few grains of microcline were found in some samples. Spicules were found in the surface sample only (1640).

Heavy fraction.—The heavy fraction is similar to that from Ninghan. The fractions contain about 60 per cent. of ilmenite and 20-30 per cent. of zircon. Dolomite is present in the first six inches. In this profile, as in many others, there seems to be a surface concentration of heavy minerals, which may be due to the action of wind in removing the lighter grains. A little sillimanite, kyanite, and garnet are among the subordinate minerals, which are present in about the same amount as in the Ninghan profile.

(iii).—LAKE BROWN.

Avon location 14343. Lat. 30° 50′, Long. 118° 28′.

Samples: 3577 (0—12″); 3578 (12—24″); 3579 (24—46″); 3586 (102—114″); 3587 (114—132″); 3588 (132—147″).

Light fraction.—The light fractions of this profile consist of 45-50 per cent. of quartz in clear, colourless grains, less than half of which are rounded. The angular grains are larger than the rounded ones in most samples. Orthoclase, in pinkish "chips," is plentiful, while there are smaller amounts of acid plagioclase, microcline, and microperthite. An interesting feature of this soil is the development of small grains of secondary material with a low refractive index (1.49 to 1.50), suggesting that opaline silica is a constituent. These grains are pale yellowish-brown in the surface fine sand, but become more reddish in the 102-114″ horizon, where they make up over 50 per cent. of the light fraction. These grains may possibly be montmorillonite (refractive index 1.516 to 1.493; Simpson, 1932), or beidellite. Below this horizon (3586) the grains have a slightly higher refractive index. Associated with these grains there are small quantities of (?) nontronite, in clear, yellowish-brown, rounded grains with refractive index over 1.56. The grains with the low refractive index may be isotropic, be weakly birefringent, or have spherulitic polarisation. The samples from the base of the profile are much paler in colour than those at the top, and the very definite ferruginous band at the 102-114″ level suggests that from the bottom to this horizon may represent an original soil developed over granitic rocks, while above this there is a secondary transported soil, the parent rock of which was also granitic, but which was modified by an accumulation of calcium carbonate, possibly augmented by saline depositions from the lake.

The heavy fractions have already been described (Carroll, 1931-32, p. 135).

The profile at Lake Brown is interesting as at the surface the pH is quite high, while at depth, it falls to about 4. Dr. L. J. H. Teakle, Plant Nutrition Officer, Dept. of Agriculture, Perth, has found that the forest soils of the Mallee zone have a neutral or practically neutral surface, a calcareous B horizon, on an acid C horizon which often contains alunite. Alunite is developed at depth in the Lake Brown profile. Mr. H. Bowley, Assistant Government Mineralogist and Chemist, considers that alunite is associated with decomposing granite, the minerals of which supplied the necessary potash. The Lake Brown fine sand contains about 45 per cent. of quartz, with smaller amounts of orthoclase, plagioclase, microcline, microperthite, muscovite, biotite, and secondary minerals, orthoclase constituting 20 to 30 per cent. of the fine said. The kaolinised portion of the fine sand may be altered mica. Chalcedony and opaline silica also occur, and these indicate great alterations of the parent material. The mineral assemblage is thus suggestive of granitic origin. It has been considered, however (personal letter, Dr. L. J. H. Teakle), that these soils cannot have been derived from granite because the amount of lime in a granite would not be sufficient to form such a calcareous B horizon. There are not many analyses of granites from Western Australia, but one from Southern Cross whose mineral composition was quartz, microcline, orthoclase, oligoclase, biotite, muscovite, and kaolin, contains 0.55 per cent. of CaO (Geol. Survey W.A. Bull. 67). Most of the other granites analysed contain a greater percentage of CaO. One acre-inch of this Southern Cross granite would contain, on the average, nearly one and one-half tons of lime, which would accumulate if the drainage was poor. It seems possible, therefore, that the Lake Brown soil has developed from a granite similar to that at Southern Cross, from which place it is not far distant. The soil contains an excess of common salt, and there seems also to be an excess of sulphate in the 1-2 water extract analyses (Teakle, 1928-29). Alunite requires the sulphate ions for its formation; this is usually considered to be obtained from percolating surface waters charged with H_2SO_4 by the oxidation of pyrites. The occurrence of alunite is too general to admit of this explanation, and it is suggested here that alunite in the soil may be formed in decomposing granitic rocks by the washing down of sulphate-bearing solutions, which were originally combined in saline waters as gypsum or some other salt.

The following table shows the mineralogical composition of the Lake Brown light fractions. The amounts of the various mineral grains present are expressed as percentages, which were obtained by traversing across the slides and counting the actual numbers of grains of different species.

Sample number.	3577	3578	3579	3586	3587	3588
Depth of sample	0″ to 12″	12″ to 24″	24″ to 46″	102″ to 114″	114″ to 132″	132″ to 147″
	%	%	%	%	%	%
Quartz	54*	44	50	16	49	54
Orthoclase	26	25	31	21	30	39
Plagioclase	2	P	P	...	2	P
Microcline	1	P	P	...	P	P
Microperthite	...	...	...	...	P	P
? Nontronite	0·5	...	...	9	17	5
? Beidellite	16	17	11	54	1	1·5
Chalcedony	...	13	8	...	...	...
Opaline SiO_2	...	P	P	...	...	...

* These percentages are approximate, the table having been simplified.
P = present.

(D).—LATERITIC SOILS.

(i).—WONGAN HILLS.

(W.A., Lat. 30° 45′, Long. 116° 35′.)

Samples: 5007 (0-8″); 5008 (8-18″); 5009/31 (18-+″).

Light fraction.—The principal mineral of the light fraction is quartz in clear, colourless, angular to sub-angular grains. Quartz is slightly more abundant in the subsoil than at the surface, and there are a greater number of rounded grains. Ferruginous material often obscures the grains in the lower parts of the profile. The inclusions noted were: rutile (sagenite webbing), zircon and (?) apatite (very minute rods). Felspars are nearly equal to the quartz in amount and are present in angular cleavage plates and worn clouded grains of a faint pinkish colour, which are readily distinguished from quartz by a lower refractive index. Many plates are rectangular, and some grains have albite twinning, but the majority are untwinned. Orthoclase and acid plagioclase are both present. Kaolinised material is pale yellow in colour and semi-opaque; some grains are finely crystalline. It is more abundant in the lower horizons than at the surface. Ferruginous material is darker in colour than the kaolin, and coats quartz and felspar grains. It gives colour to the fine sand. Spicules and other organic remains were found in the surface sample, but are not plentiful.

Heavy fraction.—The heavy fraction is abundant and contains over 50% of ilmenite. Leucoxene is fairly well developed, but only a few grains of rutile were found. Zircon, the most conspicuous subordinate mineral, occurs in two distinct types:—clear, prismatic crystals, often well worn; and brown grains partially obscured by pale, yellowish-brown, cloudy material. These latter grains may possibly be xenotime, but chemical and spectroscopic work is necessary for complete identification. The remaining grains of this fraction are epidote, tourmaline, sillimanite, andalusite, hornblende, garnet, anatase, muscovite and biotite. A little kaolinised material remains with the heavy minerals. This may represent, in part, altered mica. The abundance of zircon and lack of ferromagnesian minerals suggests that the original rock was granitic. It is interesting to note that the mineral assemblage is rather similar to that obtained from crushed gneisses and granites of the Jimperding area. If this is a true lateritic soil one would not expect to find fresh felspar grains.

(ii).—TORIYA.

KAMI-AMADA.

Ishikawa prefecture, Japan, Lat. 37° 8′ N., Long. 140° 28′ E.

Plate V., Fig. 12.

These two red soils from the Bijozin Range were found to be interesting because, although considered lateritic, they were found to be feebly radioactive (Iimori, 1932). The chemical analyses show a large amount of silica, which is accounted for by the fact that the soils were derived from diorite or granite. ". . . . . . . these lateritic soils occurring in the Bijozan Range, Ishikawa Prefecture, Japan, were probably formed, in situ, from the diorite and granite by the action of sea water on the occasion of the recent transgression followed soon after the formation of Ochigata graben. The subtropical climate of summer-time in this region would also no doubt be favourable for the progress of laterisation."

The mineralogy of the two fine sands is interesting because of: (i) the large amount of mica; and (ii) the large amount of heavy fraction consisting principally of magnetite, most of which was easily removed before further examination.

Light fraction.—In this fraction, mica is the most abundant mineral of the Toriya sample, but it is not so plentiful in the Kami-amada fine sand, where it is subordinate to quartz and felspar. Mica, though really a "heavy" mineral, tends to float off with the light fraction on account of its flaky nature. The mica is in pale yellow flakes yielding good interference figures, and is most probably muscovite. In the Kami-amada sample the mica is more altered and most of the flakes are somewhat opaque, giving the grains a very close resemblance to the semi-opaque material usually designated as kaolinised material in other samples. Quartz is about equal in amount to felspar in the Toriya sample, but more abundant in the one from Kami-amada. It is in angular to rounded grains, clear and free from inclusions. Felspar is in pinkish angular to sub-angular plates with refractive index lower than 1.53. Some of the larger plates have cleavage lines and faint twin lamellae. Felspar is not nearly as plentiful in the Kami-amada fine sand as it is in the Toriya. Most of the grains are clear, but a few are clouded with decomposition products.

Heavy fraction.—After the removal of magnetite the heavy fractions contained over 50% of ilmenite (probably with a certain amount of magnetite which did not respond to the magnet). In both fine sands rutile was more plentiful than leucoxene, and a few crystals of anatase were found in each. A conspicuous feature is the abundance of zircon, making up over

20% of the grains traversed. The habit is varied, but most of the grains are clear and non-zoned with plentiful inclusions. Broken grains are very common, but otherwise no wear or rounding is shown. The prevailing form is the elongated prism-pyramidal type, some grains being quite acicular, but others are stumpy and appear almost dodecahedral. One grain was almost tabular, the main prism being bevelled with secondary prisms. One twin was found. Some of the larger crystals are brown. A few grains of tourmaline, hornblende, epidote and (?) andalusite were also found. The plentiful zircon probably accounts for the feeble radioactivity found in these soils.

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V.—SUMMARY.

The paper deals with the mineralogical description of a series of fine sand fractions of soils from South Australia, King Island (Tasmania), Western Australia, the East Indies, and Japan.

After a mineralogical description of the samples, the results are expressed in tables, frequency numbers derived from percentages being given.

The following minerals not found in soils previously described by the author (Carroll, 1931-32) were identified:—Andesine, chromite, chalcedony, dolomite, fluorite, hypersthene, kaolinite, labradorite, ? nontronite, opaline silica, ? serpentine, and ? zoisite.

CONCLUSIONS.

1. In sedentary soils the mineralogical composition of the parent rock is indicated by the mineral grains of the fine sand fraction (Wongan Hills, W.A., Kondoparinga loam, Kuitpo, S.A.). If the soil is fairly "fresh" some indication of the texture of the parent rock is given by a microscopic examination (soil from andesite, Borneo, 928b).

2. "The new-built minerals give us the best view in the chemical processes which the soil has undergone since its building." (J. van Baren, 1928.) The formation of new minerals within the soil, such as kaolinite, the clay minerals, and the titanium minerals indicate that certain chemical processes have taken place, though it is difficult to distinguish between these processes

in the weathered rock and soil. There is a gradual transition from rock to soil, and the same weathering agents act on both, though probably more intensely on the soil. (Lappa sand, King Island; soils from Borneo.)

3. In places where there are strong winds the heavier species tend to accumulate at the surface, though there is often very little difference throughout the profile. In very "fresh" soils the lower parts of the profile show more species. (Soils from Ninghan and Gabbin, W.A., show a surface enrichment of heavy fraction.)

4. An old, well-weathered soil can often be distinguished microscopically from younger soils by a smallness of grain size (within the fine sand fraction), worn appearance of grains, *e.g.* zircon, absence of merest traces of ferromagnesians, and a greater amount of decomposed, kaolinised material. This will depend, also, on the original composition and texture of the parent rocks, and on the climate in which they have been formed. The disintegration of rocks, which is the first stage in the formation of a soil, is effected more by mechanical than by chemical processes in arid climates; in more humid regions the chemical processes may predominate (Tropical soils).

5. Species of minerals foreign to a soil may arise by the addition of salts in solution from outside sources. Thus, if there is an accumulation of calcium carbonate, as in soils of the Mallee zone, calcite and dolomite are authigenously formed, and the resulting fine sand has a different appearance under the microscope. (Ninghan and Gabbin, W.A.)

6. A microscopic examination of the fine sand indicates how the colour is distributed in the soil, and to which minerals it is due (Tropical soils). The leaching of iron to lower horizons in podsols is readily shown in this way (ferruginous band in Lake Brown soil; sands from Hundred of Kuitpo, S.A.).

7. The scarcity of species and abrasion of grains serves to differentiate secondary, transported soils, or those derived from arenaceous sediments, from sedentary, primary soils (Myponga sand, S.A., sands from King Island).

8. Definite soil types can often be recognised by a microscopic examination of the fine sand grains, the type depending on the parent rock and the weathering. Several of the types described are shown in the photomicrographs.

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DESCRIPTIONS OF THE PHOTOMICROGRAPHS.

Plate IV., Figures 1 to 6.

Heavy minerals of the fine sands from the Hundred of Kuitpo, South Australia.

Figure. 1:—*Kuitpo gravelly, sandy loam.* (Sample 1848.)—Ilmenite, tourmaline, amphibole, mica, sillimanite.

Figure 2:—*Burbrook sandy loam.* (Sample 149)—Ilmenite, rutile, small zircons, and tourmaline. The elongated rounded grain near the centre is a worn rutile crystal.

Figure 3:—*Myponga sand.* (Sample 1925.)—Ilmenite, rounded tourmaline with inclusions, rounded zircon, and a little sillimanite.

Figure 4:—*Meadows sand (alluvial).* (Sample 1919.)—There are two grade sizes, the large grains somewhat similar to those of the Myponga sand and the small ones to those of the Kondoparinga loam. The large grains are ilmenite, tourmaline, sillimanite, and zircon.

Figure 5:—*Meadows clay loam.* (Sample 1931.)—The photomicrograph shows the extremely small size of the grains, which are difficult to identify.

Figure 6:—*Kondoparinga loam.* (Sample 1927.)—Is similar to the Meadows clay loam, and contains practically the same minerals, *i.e.*, minute grains of ilmenite, tourmaline, zircon, and mica. The Meadows clay loam was probably derived from the Kondoparinga loam.

Two distinct types of parent material have given rise to the six types of soil described from the area.

Plate V., Figures 7 to 12.

Heavy minerals from various fine sands.

Figure 7:—*Naracoopa sand, King Island, Tasmania.* (Sample 2233.)—Ilmenite, zircon, tourmaline, and monazite, the latter more rounded than zircon and a little to the left of the centre of the mount.

Figure 8.:—*Red Gum soil, Manjimup, W. Australia.* (Sample 1483.)—Ilmenite, magnetite, zircon, rutile, and kyanite, which resembles the zircon crystals, but is more elongated.

Figure 9:—*Salak, near Buitenzorg, Java.* Subsoil of recent volcanic material. (Sample 156a.)—Crystalline kaolinite (top left side of mount), (?) nontronite, ilmenite, and magnetite.

Figure 10:—*Salak, near Buitenzorg, Java.* Soil from recent volcanic material. (Sample 156d.)—Ilmenite, magnetite, hypersthene (prismatic grain in lower part of mount), (?) nontronite, and euhedral quartz (just above the hypersthene).

Figure 11:—*Ninghan, Avon Location 579, W. Australia.* (Sample 1634.)—Ilmenite, zircon, rutile, amphibole, and dolomite (near edge N.E. in mount).

Figure 12:—*Kami-amada, Ishikawa prefecture, Japan.*—Ilmenite, zircon, and amphibole (just east of centre).

TABLE 2.

MINERALOGY OF THE FINE SANDS.

Locality	Manjimup, W.A.								Java.								Borneo.			
Description	Karri Soil.								Recent Volcanic.				Volcanic.		Limestone.		Gabbro.		Pd.	An.
Sample No.	1473	1474	1475	1476	1477	1478	1479	1480	156d	156c	156b	156a	993b	993a	1000c	1000b	930b	1135b	924c	928b
Depth of sample	0" to 9"	9" to 18"	0" to 9"	9" to 18"	0" to 9"	9" to 18"	0" to 9"	9" to 18"	8" to 1 M	2nd layer	3rd layer	4th layer	0" to 30cm.	30cm.	0" to 15cm.	15" to 105cm.	S	S	S	S
Heavy Fraction—																				
Ilmenite	8+	8+	8+	8+	8+	8+	8+	8+	7+	8—	8—	7+	8	8+	8	8—	7+	8	8	8—
Leucoxene	1*	1	2	1	1	1*	2	1	1	4	1	1	1	1	2	1	2	3	5	6+
Rutile	1*	1*	...	1*	1*	1*	1*	1*	1*	...	...	1	1*	1*	1*	2	1	...	1	1*
Anatase	...	...	...	...	...	...	...	...	...	...	...	...	...	1*	1	...	...	...	...	...
Magnetite	...	...	...	...	...	...	...	...	A	A	a	A	s	s	a	a	...	A	a	A
Limonite	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	6—	6—	3	1
Hematite	...	...	...	...	...	...	...	...	...	2	1	4	...	...	...	...	...	...	...	...
Chromite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	a	...
? Pyrite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Amphibole	...	...	...	...	...	...	...	...	...	...	1*	...	1*	1*	2	1*	1	...	...	P
Pyroxene	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...	5
Hypersthene ...	...	...	...	...	...	...	...	...	6	...	...	...	5	1*	4	1	...	...	...	...
Epidote	...	...	...	...	...	...	1*	1*	...	...	...	...	...	...	...	...	6	...	P	2
Muscovite	...	...	...	...	...	...	...	...	1	1*	...	...	...	...	...	...	...	...	...	...
Biotite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Nontronite ...	...	...	...	...	...	...	...	...	5	6+	7—	7	1*	2	2	7—	...	...	...	...
Andalusite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Fluorite ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Garnet	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...	...	1*	...	1*
Kyanite	1*	1*	...	...	...	...	1*	1*	...	...	...	...	...	...	2	...	...	...	...	...
Sillimanite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1*	...	...	...	...
Tourmaline ...	...	...	...	...	1*	...	1*	1*	...	1*	...	...	...	1	2	2	1	...	...	...
Zircon	4	4	3	4	2	2	4	5	2	2	2	1*	2	2	4	2	1*	...	4	2
? Zoisite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Dolomite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...	...	2	3	...	1*	...	...	...	...	...	...
Chalcedony ...	...	...	...	...	...	...	...	...	2	1	3	4	2	4	...	...	...	...	...	...
Opaline SiO_2 ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Light Fraction—																				
Quartz	8+	8+	8	8	8	8	8—	8—	5	5	5	5	5	5	6	6	...	...	...	...
Felspar	...	? P	2	P	4	4	...	...	...	...	...	...	...	...	? P	? P	...	? P	...	...
Andesine	...	...	...	...	...	...	...	...	...	...	...	...	6	6	...	...	...	...	...	...
Labradorite ...	...	...	...	...	...	...	...	...	5	5	5	5	6	6	...	...	8+	...	8+	8+
Oligoclase ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Microcline ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Microperthite ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Nontronite ...	...	...	...	...	1	P	...	P	P	P	P	P	P	P	...	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	4	5	6—	6	...	...	...	...	...	...	...	...
Kaolinised mat. ...	...	...	...	...	P	...	...	...	8	8—	8—	8—	7+	7+	...	...	5	? P	P	...
Mica	...	...	...	...	...	...	...	...	...	...	...	...	3	3	...	...	...	5	...	...
Ferruginous mat. ...	5	5	6	6—	6—	6—	5	6—	...	...	...	...	...	...	8	8	...	8+	...	P
Orthoclase	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plagioclase	...	...	...	4	...	...	7—	6+	...	...	...	...	...	...	...	...	...	...	...	...
Chalcedony ...	...	...	...	...	...	...	...	...	P	P	1	1	1	2	2	2	...	...	...	...
? Chlorite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	5
? Serpentine ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	...
Opaline SiO_2 ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Locality	Western Australia.														Japan.	
	Ninghan.						South Gabbin.					Wongan Hills.				
Description	Mallee Soil.						Mallee Soil.					? Lateritic.			? Lateritic.	
Sample No.	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	5007	5008	5009	K.A.	T.
Depth of sample	0" to 3"	3" to 12"	12" to 27"	27" to 46"	46" to 72"	72" to 75"	0" to 2"	2" to 6"	6" to 12"	12" to 24"	24" to 36"	0" to 8"	8" to 18"	18" +	S	S
Heavy Fraction—																
Ilmenite	7	7+	8—	7+	7+	8—	7+	8—	8—	8—	8—	7+	7+	7+	7+	[illegible]
Leucoxene	4	4	4	5	4	5	2	4	3	4	4	5	4	4	3	[illegible]
Rutile	2	3	1*	1	2	1	2	1*	1	2	2	1	2	3	5	[illegible]
Anatase	...	...	...	...	...	...	...	...	...	...	...	1*	1*	1	1*	[illegible]
Magnetite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Limonite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Hematite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...
Chromite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Pyrite	...	...	...	...	...	...	...	...	1*	...	...	...	...	...	...	...
Amphibole	1	2	2	2	1	2	3	2	3	...	2	1*	...	P	2	...
Pyroxene	...	...	...	...	...	...	...	...	...	...	...	...	1*	...	...	...
Hypersthene	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Epidote	2	...	...	1*	1*	1*	1*	1*	1*	...	...	4	4	2	3	...
Muscovite	...	...	...	1*	...	...	...	...	...	...	...	...	...	1	A	[illegible]
Biotite	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...	...
? Nontronite	...	1	2	P	...	...	1	...	...	2	3	6—	5	5	...	[illegible]
Andalusite	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...	...
? Fluorite	...	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...
Garnet	...	...	1*	1*	...	...	...	...	...	1*	...	...	1*	1*	...	...
Kyanite	...	...	...	...	...	...	1*	...	...	...	...	...	...	1*	...	...
Sillimanite	...	...	...	...	1*	...	1	1	...	...	...	1	...	1*	...	...
Tourmaline	1*	...	...	1*	1*	1	2	1	1	...	...	1	1	1	...	[illegible]
Zircon	7	7—	7—	7—	7	7—	7—	6+	7—	6	6+	6—	6+	6	7—	[illegible]
? Zoisite	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
Dolomite	5	...	...	...	...	...	5	5	...	...	...	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Chalcedony	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...	...
Opaline SiO_2	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...
Light Fraction—																
Quartz	6—	6	6+	6+	7	7+	7	7	7	7	7	7+	7+	8—	7	[illegible]
Felspar	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Andesine	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Labradorite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Oligoclase	...	...	...	...	...	...	...	...	...	P	P	...	...	...	...	...
Microcline	...	...	...	...	...	...	...	P	...	...	...	...	...	...	...	...
Microperthite	...	P	P	...	...	...	...	...	...	...	...	...	...	...	...	...
? Nontronite	8—	8—	7+	7+	7—	6—	7	7	7	7	7	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Kaolinised mat.	5	P	P	P	P	P	P	P	P	P	P	2	4	4	P	...
Mica	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7+	[illegible]
Ferruginous mat.	P	P	P	P	P	...	...	...	...	...	...	...	P	P	...	...
Orthoclase	4	6—	6—	6—	6	6—	6—	6—	6—	6	6	7	7	7—	6—	[illegible]
Plagioclase	...	4	5	5	5	6	5	5	5	5	5	5	4	4	...	...
Chalcedony	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Chlorite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Serpentine	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Opaline SiO_2	...	P	P	P	...	...	...	...	...	...	...	...	...	...	...	...

Pd = Peridotite.
An = Andesite.
S = Surface.

P = Present.
A = Abundant.
a = fairly plentiful.

s = Scarce.
Ka = Kami-amada.
T = Toriya.

	Western Australia.														Jap
	Ninghan.						South Gabbin.					Wongan Hills.			
An.	Mallee Soil.						Mallee Soil.					? Lateritic.			? Late
28b	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	5007	5008	5009	K.A.
S	0″ to 3″	3″ to 12″	12″ to 27″	27″ to 46″	46″ to 72″	72″ to 75″	0″ to 2″	2″ to 6″	6″ to 12″	12″ to 24″	24″ to 36″	0″ to 8″	8″ to 18″	18″ +	S
8—	7	7+	8—	7+	7+	8—	7+	8—	8—	8—	8—	7+	7+	7+	7+
6+	4	4	4	5	4	5	2	4	3	4	4	5	4	4	3
1*	2	3	1*	1	2	1	2	1*	1	2	2	1	2	3	5
...	...	...	...	...	...	...	...	...	...	...	...	1*	1*	1	1*
A	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	1*	...	...	...	...	...	...
P	1	2	2	2	1	2	3	2	3	...	2	1*	...	P	2
5	...	...	...	...	...	...	...	...	...	...	...	...	1*	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	2	...	...	1*	1*	1*	1*	1*	1*	...	...	4	4	2	3
...	...	...	...	1*	...	...	...	...	...	...	...	...	...	1	A
...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...
...	...	1	2	P	...	...	1	...	...	2	3	6—	5	5	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...
...	...	...	...	...	...	...	...	1*	...	...	...	...	...	...	...
1*	...	...	1*	1*	...	...	...	...	...	1*	...	...	1*	1*	...
...	...	...	...	...	...	...	1*	...	...	...	...	...	...	1*	...
...	...	...	...	...	1*	...	1	1	...	...	...	1	...	1*	...
...	1*	...	...	1*	1*	1	2	1	1	...	...	1	1	1	...
2	7	7—	7—	7—	7	7—	7—	6+	7—	6	6+	6—	6+	6	7—
...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
...	5	...	...	...	...	...	5	5	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...
...	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...
...	6—	6	6+	6+	7	7+	7	7	7	7	7	7+	7+	8—	7
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8+	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	P	P	...	...	...	...
...	...	...	...	...	...	...	...	P	...	...	...	...	...	...	...
...	...	P	P	...	...	...	...	...	...	...	...	...	...	...	...
...	8—	8—	7+	7+	7—	6—	7	7	7	7	7	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	5	P	P	P	P	P	P	P	P	P	P	2	4	4	P
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7+
P	P	P	P	P	P	...	...	...	...	...	...	...	P	P	...
...	4	6—	6—	6—	6	6—	6—	6—	6—	6	6	7	7	7—	6—
...	...	4	5	5	5	6	5	5	5	5	5	5	4	4	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	P	P	P	...	...	...	...	...	...	...	...	...	...	...

Scarce.
Kami-amada.
Toriya.

PLATE IV.

Fig. 1. × 40.

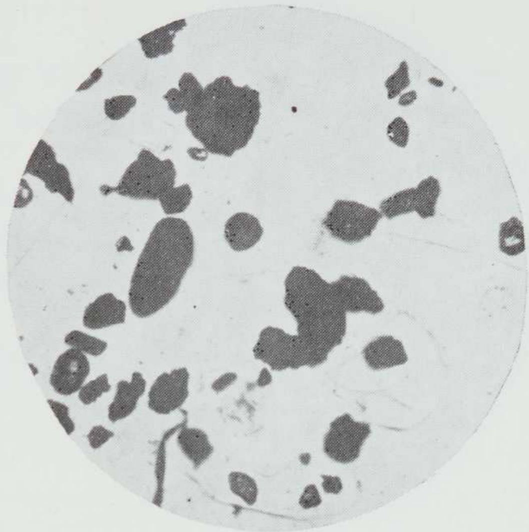

Fig. 2. × 40.

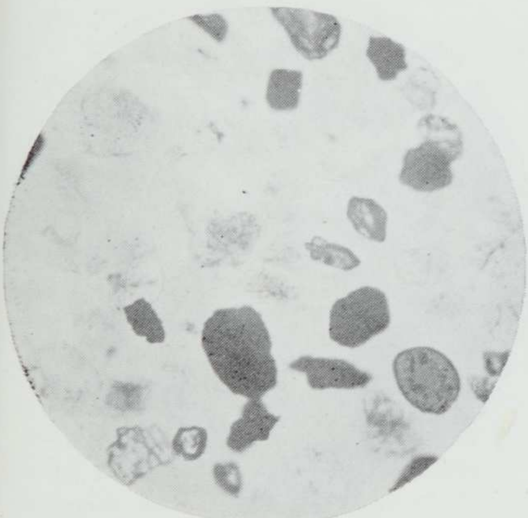

Fig. 3. × 47.

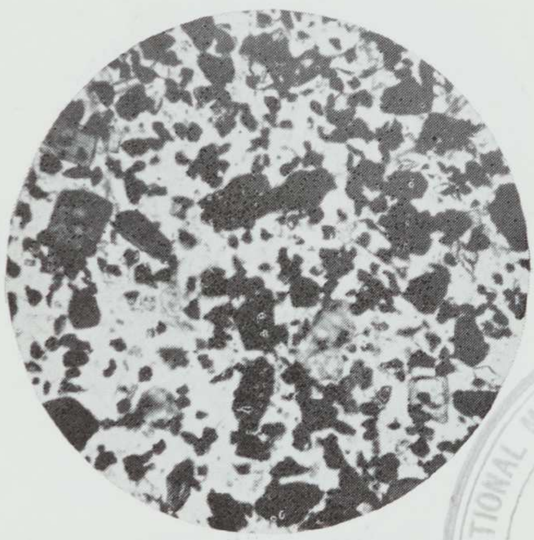

Fig. 4. × 38.

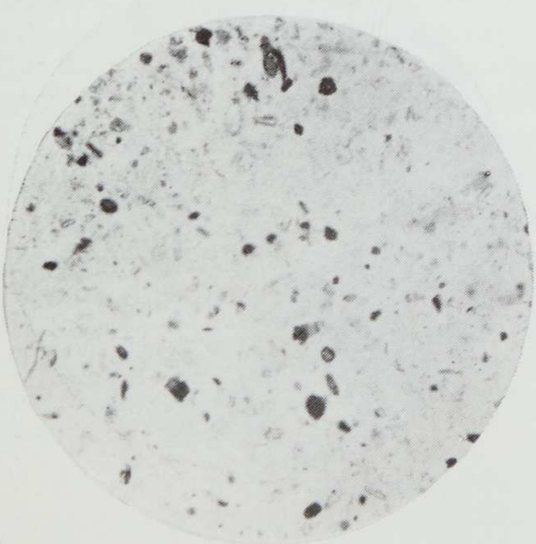

Fig. 5. × 40.

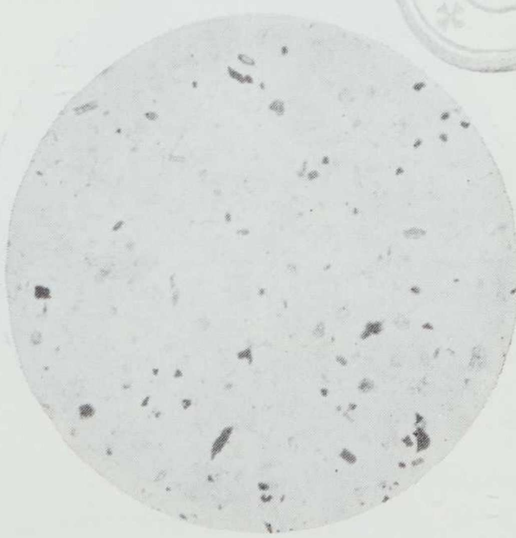

Fig. 6. × 40.

[*Photo.*, *H. J. Smith.*]

PLATE V.

Fig. 7. × 40.

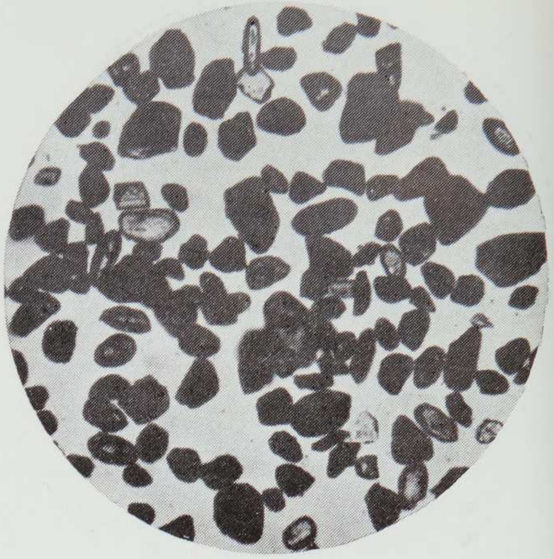

Fig. 8. × 40

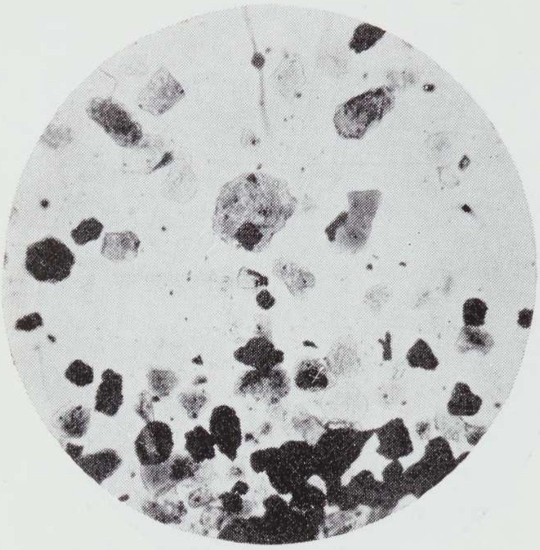

Fig. 9. × 34.

Fig. 10. × 38.

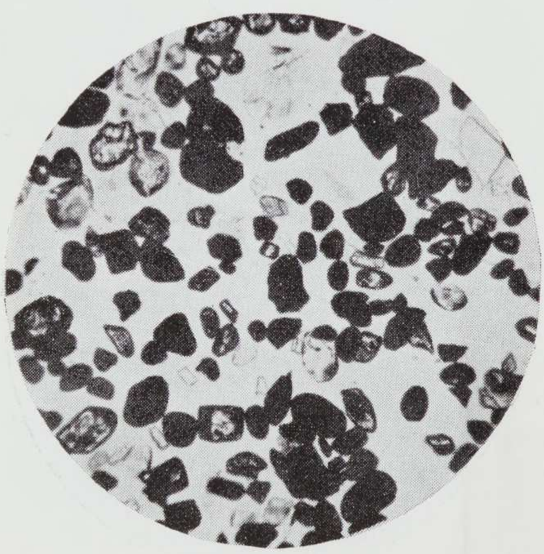

Fig. 11. × 47.

Fig. 12. × 40.

[*Photo.*, *H. J. Smith.*]

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